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Numerical Modeling on the Structural Performance of RCC Beams Made With SCC Produced By RCA as Coarse Aggregate

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Abstract: ***Economical status of a country mainly depends on the amount of investments made on the infrastructure development. Most of the high rise buildings constructed in our country have grown old and are being demolished or strengthened. The construction of new high rise structures will require huge amount of source materials like cement and fine and coarse aggregate. Especially, 8 – 12 billion tons of natural aggregates were consumed annually by the construction industry around the world. This may result in increased demand on the source materials and leading to various socioeconomic problems. On the other hand, disposal of concrete debris from the demolished high rise concrete structures requires large land area for open disposal. In order to solve these two problems, concrete debris from the demolished structures are processed and used as an alternative material to the coarse aggregate. The main objective of this study is to determine the structural performance of recycled concrete aggregate in self-compacting concrete (SCC) as a replacement for coarse aggregates.RCA is used as substitute for coarse aggregate at percentages ranging from 0 to 100%, at an interval of 20%. To evaluate the structural performance of RCC beams prepared with fibre reinforced SCC of grade M40 was tested experimentally and numerically. Numerical investigation on RCC beams was done in the simulation software ANSYS packages.***

Keywords: Self Compacting Concrete, Recycled Concrete Aggregate, Numerical Modeling, Structural Performance.

I. INTRODUCTION

A. Self compacting concrete (SCC)

In recent days, SCC has seen remarkable developments in the construction industry [3&4]. The main advantage of using SCC is that concrete can flow under its own weight and get compacted without any requirement of external vibration, congested reinforcements and complexity of formwork. By considering these benefits, SCC was utilized in many countries for construction.

B. Construction & Demolished Wastes (C & D Waste)

C & D wastes often contain concrete, metals, wood and plastics. It is very difficult to handle because it is massive and inert, and it is mixture of materials with specific properties. It is also difficult to prefer a proper disposal method. With the emergence of sustainable practices in the construction industry, issues of production and waste management have been key to achieving the enduring goals of our common future. The 3R philosophy is extremely useful for treating C & D waste.

Around the world, 2 to 3 billion tons of building waste was generated, out of which 30 to 40 % is concrete. Given the rapid growth of construction activity in India, the generation of C & D waste should be linked to the growth of the construction sector and related issues. Different components of C & D waste was shown in Figure 1 [TIFAC (2000)].

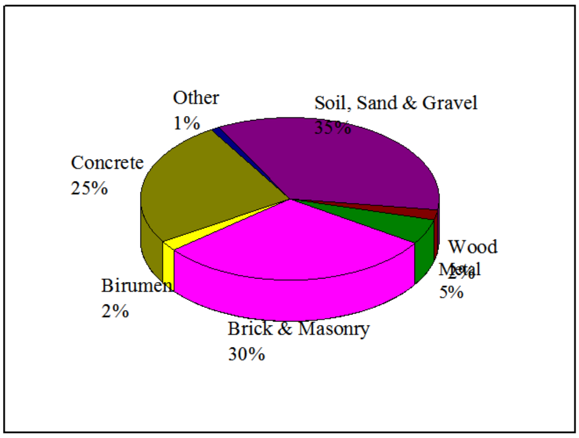

Fig. 1. Different Components of C & D Waste

C. C & D Waste Estimation

In India, production rate of C & D waste is 1.45crore tones/year [Pappu et al. (2007)]. The growth of municipal solid waste generation in India up to 2047 is predicted and shown in Figure 2 [Singhal et al. (2001)].

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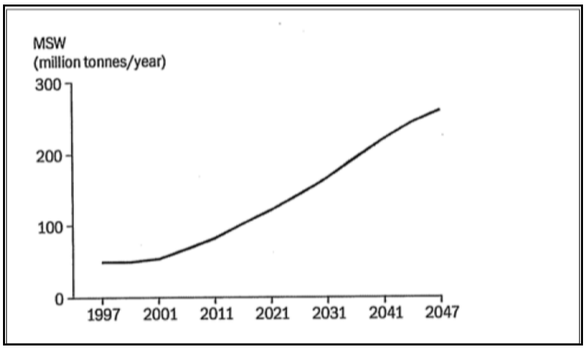

Fig. 2 MSW Generations in India

D. Recycled Concrete Aggregate

Growing demand and reduction in the availability of natural aggregates have necessitated the search for new materials as substitutes for coarse aggregate. Concrete debris from the construction industry was processed and used as an alternative material for coarse aggregate, which possesses properties similar to those of coarse aggregate. RCA is an alternative to the two types of aggregates that can be used in concrete production [Mullick.A.K (2014)]. The sequential processes involved in the production of RCA are briefly shown in Figure 3.

Fig. 3. Production of RCA

II. MATERIALS USED

The different properties of various ingredients of concrete are tabulated in Table 1 to 4.

Table- 1: Properties of Cement and Fly ash

Parameter		Cement	Fly ash
Color		Grey	Dark grey
Specific Gravity		3.13	2.10
Fineness (m^2/kg)		310	475
Consistency (%)		29	-
Setting time (Minutes)	Initial	43	-
	Final	340	
Bulk density (kg/m^3)		-	1157
Fineness		-	18.2

Table- 2: Chemical Properties of Cement and Fly ash

Component	OPC 53	Fly ash
K_2O	0.62	0.74
Na_2O	0.44	0.42
SO_3	1.41	0.22
MgO	2.15	1.73
Fe_2O_3	3.49	7.36
Al_2O_3	6.86	26.80
CaO	63.11	3.23
SiO_2	24.51	54.01

Table- 3: Properties of Aggregates

Parameter	FA	CA	RCA
Grade	II	-	-
Size (mm)	< 4.75	20	20
Specific Gravity	2.55	2.75	2.44
Fineness (m^2/kg)	2.56	-	
Fineness modulus	-	6.95	6.55
Bulk density (kg/m^3)	1895	1487	1251
Water absorption	1.41	0.82	3.47

Table- 4: Properties of Synthetic Fiber

Parameter	Value
Fiber Type	Mono Fiber
Pattern	Synthetic
Fiber Type	Polypropylene Fiber
Length (mm)	12
Dia (mm)	0.034
Aspect Ratio	400
Unit Weight (kN/m^3)	9.1
Young's Modulus (MPa)	2800
Tensile Strength (Mpa)	650
Fiber Type	Mono Fiber
Pattern	Synthetic

III. MIX PROPORTION

Mix design for M40 grade SCC was prepared with partial replacement of coarse aggregate by RCA in the proportions of 0 - 100% at intervals of 20%. Synthetic fibers were also incorporated at different dosages of 0%, 0.25%, and 0.5% by volume of concrete.

Table- 5: Mix Proportions

Mix ID	C	FA	CA	RCA	A	W	SP	W/C
	kg/m^3						lit/m^3	
CC	460	630	1159	-	-	184	-	0.4
SCC	521	782	834	0	126	198	3.83	0.38
RCASCC20	521	782	667	167	126	198	4.79	0.38
RCASCC40	521	782	500	334	126	198	4.79	0.38
RCASCC60	521	782	334	500	126	198	4.79	0.38
RCASCC80	521	782	167	667	126	198	4.79	0.38
RCASCC100	521	782	0	834	126	198	4.79	0.38

On the basis of the test results, it was concluded that 40% replacement of RCA and 0.5% addition of synthetic fiber would be considered as optimum percentage of usage.

IV. STRUCTURAL PERFORMANCE OF RCC BEAM

Beam specimens with the dimension of 150 x 200 x 2000 mm were cast with a clear cover of 25mm and they were tested under 28 days of curing period.

Table -6: Reinforcement Detailing

Reinforcement	Detailing			Yield stress (σ_y) (MPa)
	No. of Bars	Dia (mm)	Spacing (mm)	
Tension zone	2	20	-	415
Compression zone	2	20	-	415
Stirrups	-	8	200	415

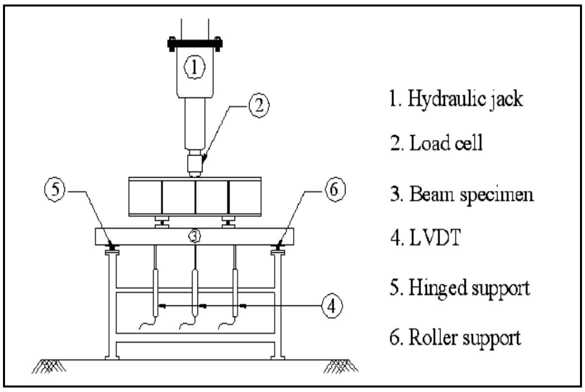

Fig. 4: Experimental Test Setup

The values of deflections due to corresponding loads were recorded. The test results are cited in Table 7.

Fig. 5: Testing of RCC beams

Table- 7: Flexural Strength Test on RCC Beams

Load (kN)	Mid span Deflection (mm)		
	SCC	RCASCC40	RCASCC100
0	0	0	0
1	0.1	0.83	0.32
5	0.24	0.99	0.49
11	0.38	1.67	0.72
15	0.59	2.1	0.89
19	0.71 (F)	3.02	1.05
21	0.84	3.87	1.26 (F)
23	0.98	3.54	1.75
24	1.15	3.99	2.29
25	1.47	4.17	2.58
26	1.53	4.39	2.79
27	1.77	4.78 (F)	3.11
30	2.17	5.11	3.43
38	3.76	7.01	5.08
45	4.94	8.99	6.68
51	6.25	13.76	7.99
59	7.58	16.93	9.1
63	8.47	19.59	10.89
66	9.19	20.79	11.24
68	10.21	21.75	12.85
70	11.38	23.88	13.38
72	11.83	25.07	14.16
73	12.11	26.12	14.97
75	12.84 (U)	27.00	15.87
79	-	28.07	16.49
80	-	29.53	17.24
83	-	31.01	18.17 (U)
85	-	32.56	-
87	-	34.18	-
88	-	35.89	-
91	-	37.69 (U)	-

[*F – First Crack; **U – Ultimate Crack]

The structural behavior of RCC beams made with fibre-reinforced self compacting concrete was studied by replacing the coarse aggregate with recycled concrete aggregate. Load vs deflection curve was drawn for RCA replacement of 0%, 40% and 100% as illustrated in Figure 6. The first crack was initiated in RCC beams of RCA replacement of 0%, 40% and 100% by 19kN, 27kN and 21kN respectively.

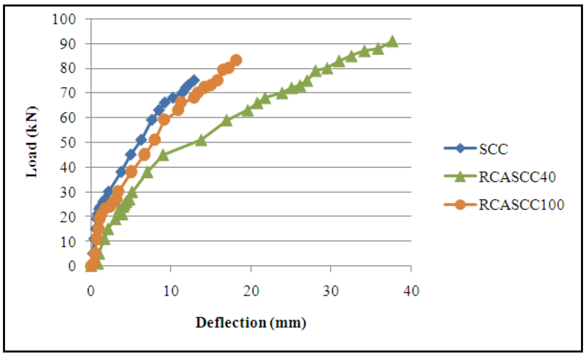

Fig. 6: Load vs Deflection Curve

Table- 8: Flexural Behavior of RCC Beams

Mix ID		SCC	RCASCC40	RCASCC100
First Crack Load P_{cr} (kN)		19	27	21
Deflection at First Crack (mm)	L/3	0.53	4.12	1.08
	L/2	0.71	4.78	1.26
	L3	0.52	4.16	1.1

Ultimate Load P_u (kN)		75	91	83
Deflection at Ultimate Load (mm)	L/3	11.55	35.27	17.03
	L/2	12.84	37.69	18.17
	L3	11.59	35.31	16.94
P_{cr}/P_u	(%)	25.33	29.67	25.3
Mode of Failure		Flexural		
Stiffness	(kN/mm)	5.84	2.41	4.57

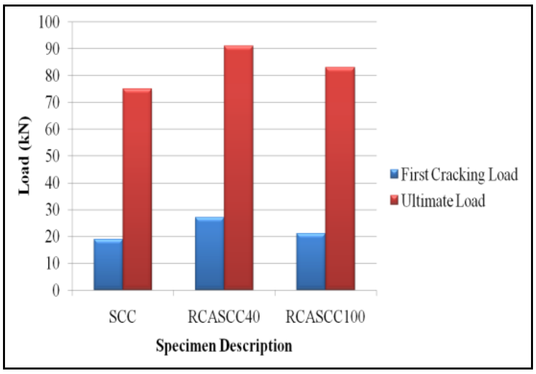

Fig. 7: Cracking Behavior of RCC Beams

V. NUMERICAL INVESTIGATION ON RCC BEAMS

Numerical investigation was one of the best ways to predict the behavior of RCC beams under two point loading. ANSYS package was employed to analyse the behavior of RCC beams in flexural strength test, and it is useful to analysea large number of beams within a short duration with higher accuracy. A variety of elements incorporated from ANSYS library for the analysis of RCC beams areillustrated in Table 9, and the material properties for each element areshown in Table 10.

Table- 9: Elements used in FEA

Element	Type of element	Beam Components
SOLID65	Brick	Concrete
LINK8	Discrete	Reinforcement
SOLID 185	Brick	Bearing Plates

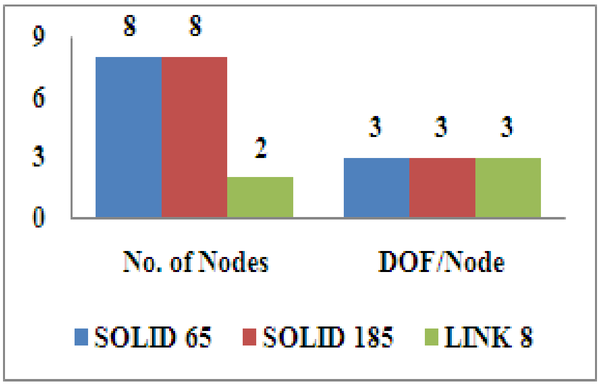

Fig. 8. Element Description

Table- 10: Material Properties assigned for Elements in ANSYS

Property	Units	SOLID65	SOLID185	LINK8
E	MPa	33900	2000000	200000
Ult. Comp. Strength		58.6	-	-
Ult. Tensile Strength		4.75	-	-
Yield Stress		-	-	415
f_{ck}		40	-	-
µ	-	0.21	0.31	0.3
Density	kg/m^3	2400	-	-
Shear Transfer Parameter	-	0.4	-	-

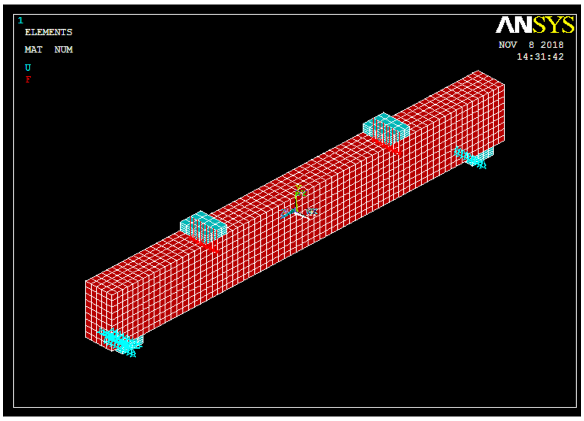

Fig. 9: Modeling of RCC Beams in ANSYS

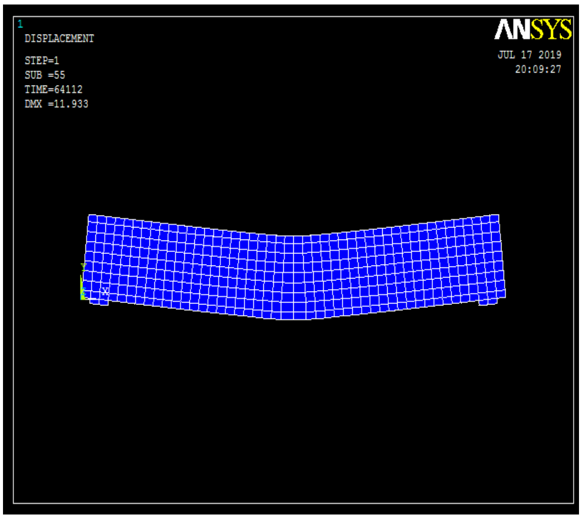

Fig. 10: Deflection Behavior of RCC Beams in ANSYS

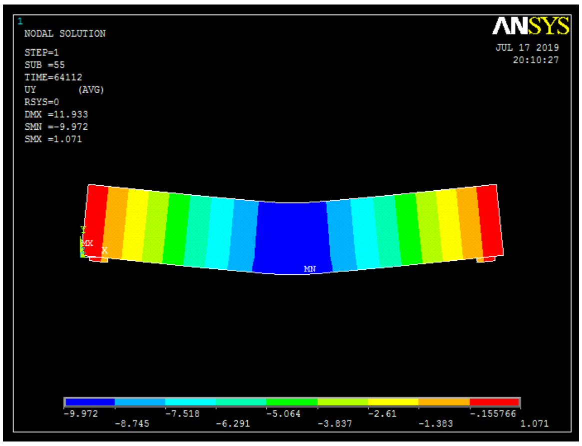

Fig. 11: Stress variation along the length of RCC beam in ANSYS

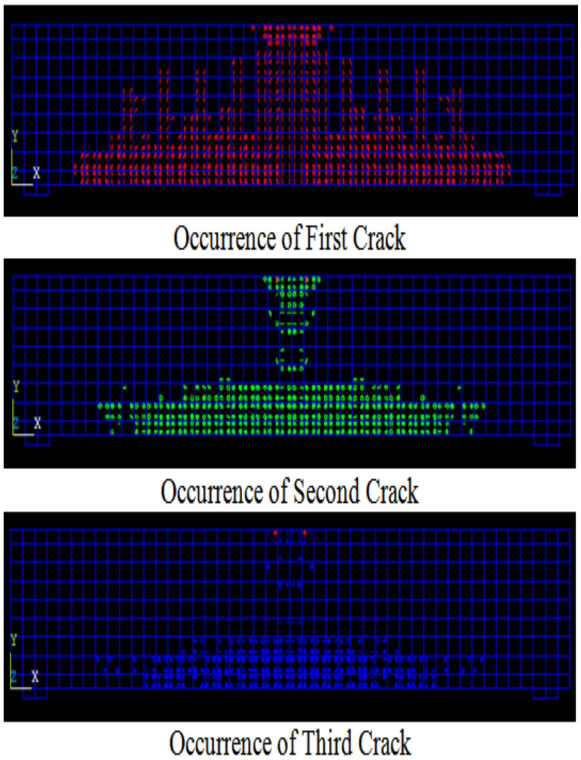

Fig. 12: Crack Propagation in RCC beams

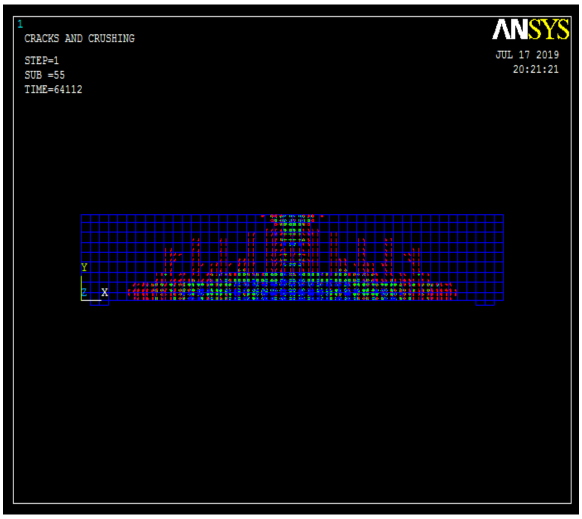

Fig. 13: Crack behavior of RCC beam in ANSYS

Table- 11: Comparison of Experimental and Numerical Results

Mix ID		SCC	RCASCC40	RCASCC100
First Crack Load P_{cr}(kN)	Exp.	19	27	21
	FEA	21	29.5	25.5
$P_{cr\text{-}Exp}$ / $P_{cr\text{-}FEA}$		0.9	0.92	0.82
Ultimate loadP_u(kN)	Exp.	75	91	83
	FEA	85	103	90
$P_{u\text{-}Exp}$ / $P_{u\text{-}FEA}$		0.88	0.88	0.92

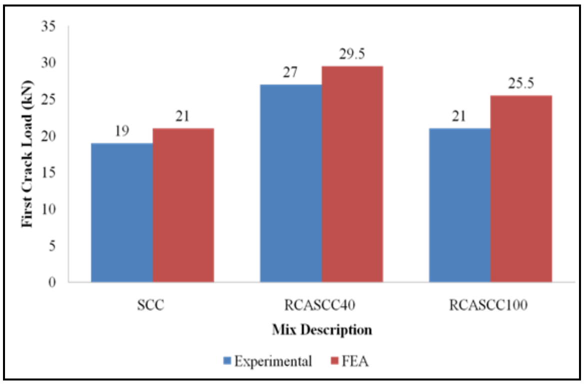

Fig. 14: Comparison of First Crack Load from Experimental vs Numerical

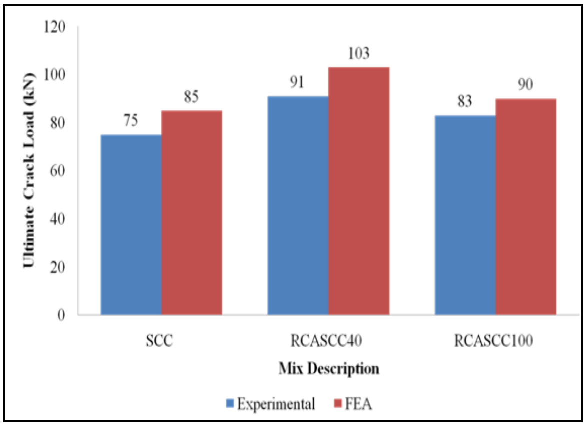

Fig. 15: Comparison of Ultimate Crack Load from Experimental vs Numerical

VI. CONCLUSIONS

The present paper briefly investigated the structural performance of RCC beams made with fibre reinforced SCC, while coarse aggregate was replaced by RCA at varying percentages.

- It shows that the current sustainable concrete contains a processed RCA that perfectly replaces the natural coarse aggregate.
- RCA-made SCC mixes have reached the target strength in all mixes and met the guidelines specified in the EFNARC specifications.
- Results predicted from numerical investigation match with those from experimental investigations.
- Full replacement of coarse aggregate by RCA is possible to produce SCC of M40 grade.
- The increase in addition of RCA as coarse aggregate in SCC results in reduction in the ultimate load carried by the reinforced concrete beams andthe deflection produced at the ultimate load was high compared to the conventional SCC.

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